EXCITATION AND PROPAGATION OF SHORT-PERIOD SURFACE WAVES IN YOUNG SEAFLOOR

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ABSTRACT

In seafloor younger than about 20 Ma, the lithosphere is not well-developed and Sn does not propagate efficiently. In young seafloor, however, S waves or normal modes of 3-to-6-s period trapped in the crust are strongly excited by shallow earthquakes and propagate to large distances with little attenuation. Young seafloor typically has few sediments, so there is no low-velocity, low-Q layer at the surface to trap and attenuate these crustal phases. These waves are essentially the equivalent of Lg in continental settings, although because there is no granite in the oceanic crust, they might better be dubbed Lb, with b for basalt. Like T-phases, Sn, and 15-to-20-s period Rayleigh waves, these Lb waves are dispersed and/or scattered arrivals. Unlike these other phases, Lb is close to the microseism peak, yet, because they are so effectively excited by shallow earthquakes and so little attenuated, they stand out above the noise level as one of the most prominent signals on ocean-bottom seismometers (OBS).

In the MELT Experiment, 51 ocean-bottom seismometers were deployed for a period of approximately six months, from November 1995 to May, 1996, in two linear arrays extending about 800 km across the East Pacific Rise at 15 to 18°S. Recordings of regional earthquakes on this array shows that short-period Love and Rayleigh waves (~3-6 s) are excited that travel with velocities characteristic of the upper crust (~ 3 km/s). The Love waves are normally dispersed with continuous frequency variation from 3 s to long periods, but Rayleigh waves appear to have a gap between 12-to-15 s fundamental mode waves with much of their energy concentrated in the water column and the 5-to-6 s higher mode waves. These latter waves, the short-period, crustal surface waves, Lb, show very little attenuation. Even at 3200 km away from an earthquake on the northern East Pacific Rise, they still are a prominent phase, despite lying in the peak of the microseismic noise. The excitation and propagation characteristics of these waves are being explored.

Key Words: Surface waves, attenuation, ocean-bottom seismometers

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Introduction

In ocean basins, there are three primary types of seismic waves traveling in low attenuation waveguides that provide good signal-to-noise ratios for small events at large distances: T-phases, Sn, and 15-to-20-s period Rayleigh waves. T-phases, of course, propagate in the SOFAR channel and Sn in the lithospheric mantle. Much of the energy of shorter period Rayleigh waves is concentrated in the water column, which is high Q, and the remainder, except where there are thick sediments, is primarily in the dehydrated, high-Q, lower crust and uppermost mantle. T-phases and 15-to-20-s period Rayleigh waves are efficiently excited by shallow earthquakes and explosions in the oceanic crust and also fall in low-noise windows that are unaffected by oceanic microseisms or long-period, water, gravity waves (Webb, 1998). Thus, these waves are primary candidates for detecting, locating and discriminating explosions from earthquakes in oceanic settings.

Less well known is another type of wave and waveguide in young seafloor. In seafloor younger than about 20 Ma, the lithosphere is not well-developed and Sn does not propagate efficiently. In young seafloor, however, S waves or normal modes of 3-to-6-s period trapped in the crust are strongly excited by shallow earthquakes and propagate to large distances with little attenuation. Young seafloor typically has few sediments, so there is no low-velocity, low-Q layer at the surface to trap and attenuate these crustal phases. These waves are essentially the equivalent of Lg in continental settings, although because there is no granite in the oceanic crust, they might better be dubbed Lb, with b for basalt (or just keep the g for gabbro). Like T-phases, Sn, and 15-to-20-s period Rayleigh waves, these Lb waves are dispersed and/or scattered arrivals. Unlike these other phases, Lb is close to the microseism peak, yet, because they are so effectively excited by shallow earthquakes and so little attenuated, they stand out above the noise level as one of the most prominent signals on ocean-bottom seismometers (OBS).

Data Set

In the MELT Experiment, we deployed 51 ocean-bottom seismometers for a period of approximately six months, from November 1995 to May, 1996 (Forsyth et al., 1998). They were deployed in two linear arrays (Figure 1) extending about 800 km across the East Pacific Rise at 15 to 18°S. During the experiment, we recorded three of the French nuclear tests in Polynesia, several earthquakes at regional distances along the East Pacific Rise, and many teleseismic events (Figure 2). In addition, many very small local events were recorded and located using T-phases. This experiment represents the largest array of ocean-bottom seismometers ever deployed and, at least at the time of the experiment, the longest duration experiment using portable OBSs.

Fifty of the 51 OBSs were equipped with three-component, Mark Products L4C 1-Hz seismometers as well as either a hydrophone or Cox-Webb differential pressure gauge (DPG) to record pressure variations. One was equipped only with a hydrophone. Stable temperatures at the seafloor help make it possible to record long-period signals reliably out to periods of 60 s and more. Several methods for deploying, levelling, filtering and recording were employed by four instrument groups. Data were recorded at either 16 or 32 samples per second, except during the seismic refraction phase of the experiment when higher rates were employed. Instrument response characteristics were derived for each type of instrument and tested by comparing corrected waveforms of earthquakes at adjacent stations. The OBSs operated independently on battery power and no data was transmitted back to the recording ship. After correction for clock drift, the

timing errors are estimated to be less than 0.01 s. After reaching the seafloor, each OBS was located precisely by acoustically ranging to a transponder from the ship, which was navigated using the P-code Global Positioning System (GPS). Locations are estimated to be accurate within about 10 m. At the end of the experiment, acoustic signals were sent to release the weights (anchors) of each OBS. Fifty of the 51 OBSs were recovered. To reduce noise, in three of the four basic OBS designs the seismometer package was deployed separately from the recording package after reaching the seafloor. This mechanical deployment procedure was the most serious instrumental problem in the experiment. The seismometer package did not deploy properly at 20 sites. Seismic records from these OBSs were limited to the waves with pressure components.

This unique data set will provide a good indication of the nature of scattering from regional events by looking at the variability of waveforms from station to station. The aperature is wide enough to the north and south to allow good locations of events at regional distances and long enough to measure apparent attenuation. Propagation characteristics can be estimated both within the array and between the sources and various elements of the array.

Example Seismograms

Figure 3 shows seismograms from an earthquake at the northern end of the Easter microplate at a distance of about 660 km, filtered in different bands. At regional distances, the distinction between surface waves and body waves is blurred, but there is clear dispersion on the transverse component between waves of ≥ 10 s period that predominantly arrive at times corresponding to mantle shear velocities (~4 km/s beneath young seafloor) and waves of period ≤ 5 s that travel with velocities characteristic of the upper crust (~ 3 km/s). Following the simply dispersed portion of the seismogram is a long train or coda of scattered, short-period surface waves. The dispersed part is predominantly Love waves on the transverse component, but there is a Rayleigh wave component at the shorter periods that shows up on the vertical component, presumably consisting of higher mode waves trapped in the crust.

There is a window (Figure 4) in the pressure noise field between the microseism peak and the pressure variations associated with long-period internal gravity waves that allows the longer Rayleigh waves to be detected. In 3 km of water, the window lies between about 10 and 30 s; in shallower water, the window closes because the depth of penetration of the gravity waves is roughly proportional to period. The short-period, crustal surface waves, Lb, show very little attenuation as long as they propagate in regions with little sediment. At 3200 km away from an earthquake on the northern East Pacific Rise, they still are a prominent phase (Figure 5) at 5 s period, despite lying in the peak of the microseismic noise (Figure 4).

Excitation of Seismic and Hydroacoustic Waves in Oceanic Environment

Our expectation is that the combination of relative excitation of T-phases, Lb, and 15-to-20 s Rayleigh waves will prove to be a powerful discriminant between explosions and shallow earthquakes in the same manner as standard Ms:mb or MLg:mb discriminants on land. We will explore that possibility first with empirical comparisons with the recordings of the French tests and the earthquakes on the array of MELT Experiment OBSs. To understand the results, we will model excitation and propagation of the waves; first with standard reflectivity and normal mode codes for a layered earth, then with a 3-D numerical code to

understand the role of lateral heterogeneities in crustal structure and water depth. We will concentrate primarily on exploring the effect of crustal heterogeneities on the propagation of the Lb phase.

One of our goals is to determine effective attenuation coefficients as a function of frequency. We suspect that Lb is effectively excited only by very shallow events in oceanic crust, because the velocities indicate that it is primarily a crustal phase. Part of our task will be to see how well it is excited by events in subduction zones along the Cocos and Nazca plate boundaries. We also do not know how well it is transmitted in older seafloor, where alteration may decrease Q in the basaltic crust and the buildup of sediments may trap and attenuate the waves. We have seen short-period signals of this type from East Pacific Rise events recorded on continental stations near the west coast of South America, but have not explored this phenomenom systematically in terms of propagation efficiency as a function of age of seafloor or sediment thickness.

References

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Webb, S.C., Broadband seismology and noise under the ocean, Rev. Geophys., 36, 105-142, 1998.

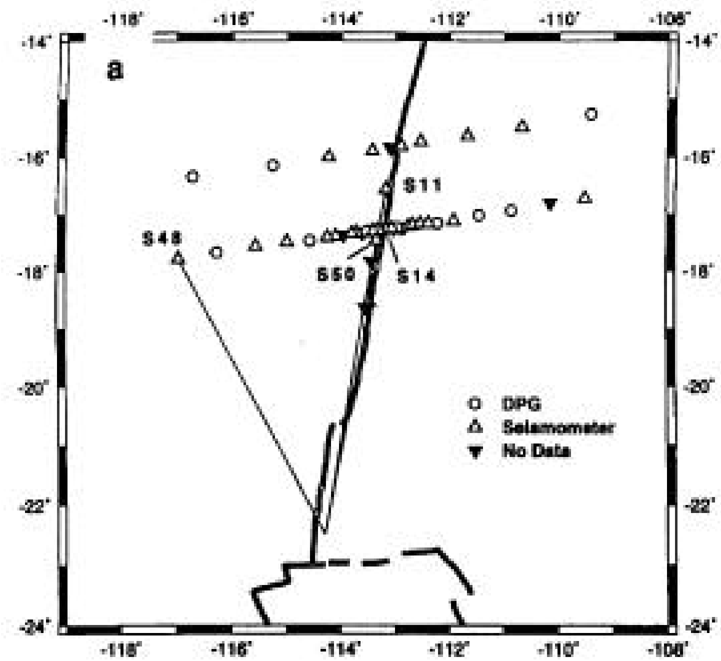

Figure 1. Location of ocean-bottom seismometers (OBSs) in the MELT Experiment. Plate boundaries of the East Pacific Rise and Easter Microplate are shown as double-wide lines. Epicenter of source of seismograms in Fig. 3 is shown just north of microplate.

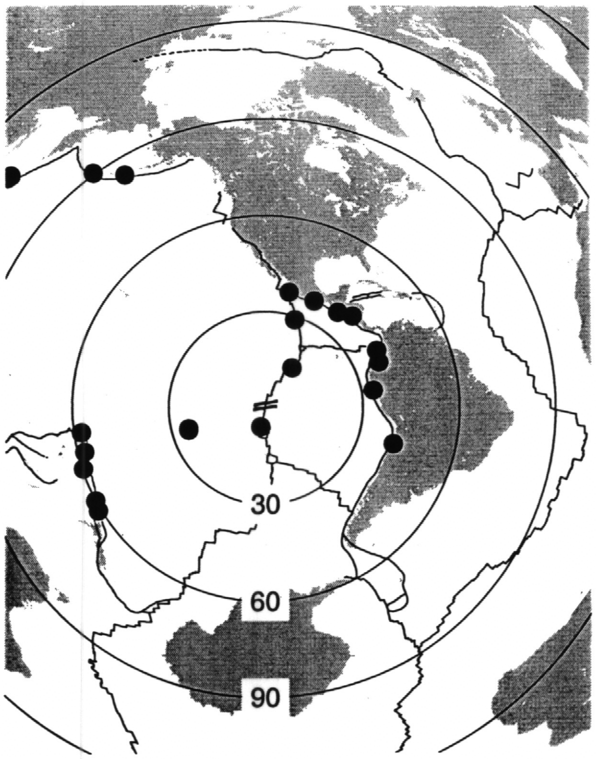

Figure 2. Location of the array and some of the events recorded during the ~ 6-month recording period of the MELT Experiment.

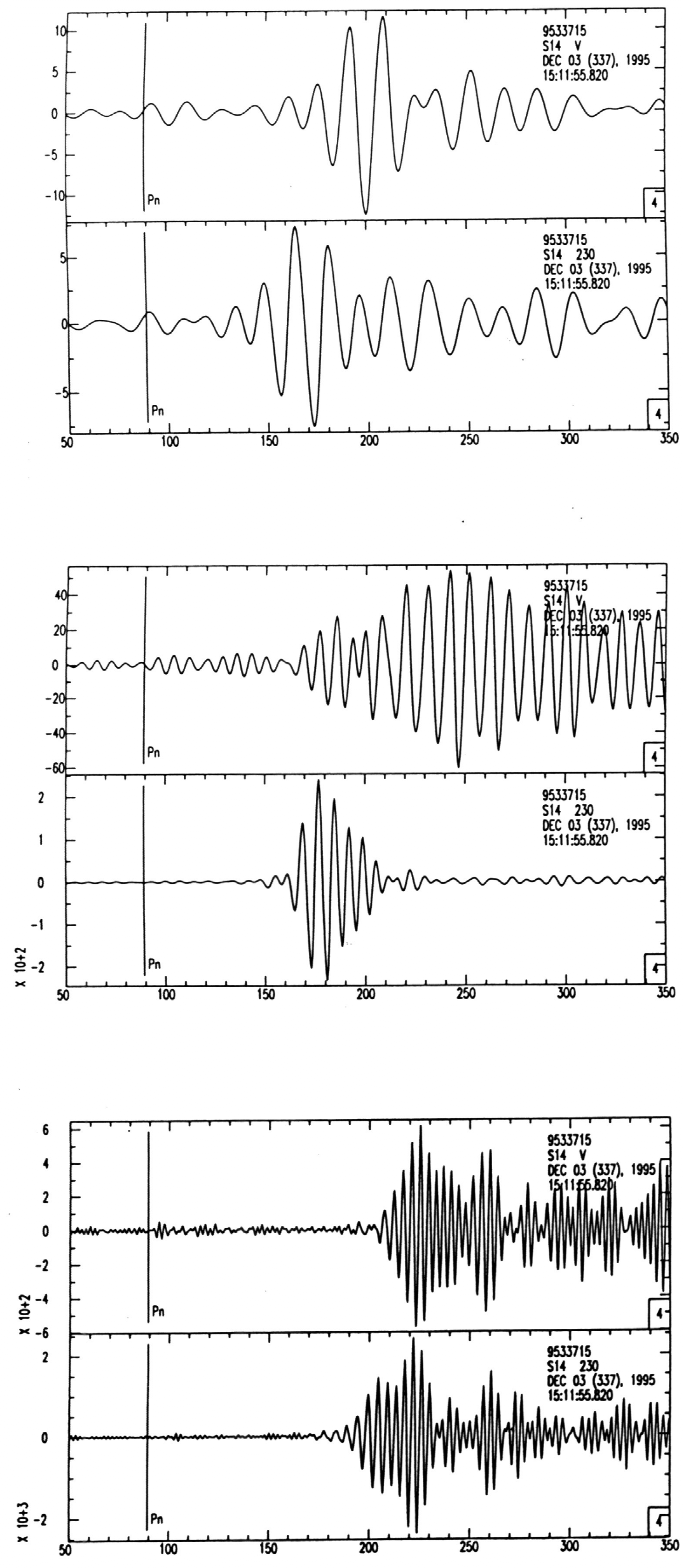

Figure 3. Seismograms recorded on an OBS 660 km from an earthquake at the northern end of the Easter microplate (mb 4.7). Upper record in each pair is the vertical component, lower record the transverse component. Top pair, filtered from 0.04 to 0.07 Hz, middle pair from 0.08 to 0.15, bottom pair from 0.15 to 0.5 Hz. Separate vertical scale for each panel. Note that at long periods (top panel), the vertical component is twice as large as the horizontal (fundamental mode Rayleigh wave dominates the vertical component), but at shorter periods, the horizontal component is much larger. Middle panel shows highly dispersed Rayleigh wave on the vertical component, due to water layer and dispersion of Love wave in transition from a mantle to a crustal phase. Energy at short periods (bottom panel) must be trapped in crust; 220 s corresponds to group velocity of 3 km/s. Horizontal component to about 230 s appears to be simply dispersed, fundamental mode Love wave; later arrivals seem to be scattered, multiple arrivals. Vertical component at short periods must be composed of higher mode Rayleigh waves. Collectively we are calling this packet of energy Lb.

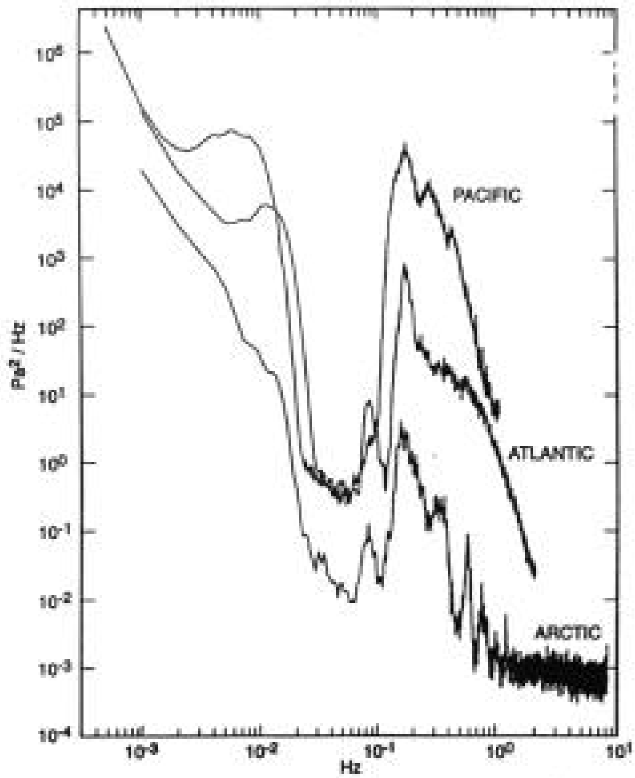

Figure 4. Comparison of noise spectra for pressure component in different oceans (from Webb, 1998). Note "hole" that allows Rayleigh waves and other signals to be detected in the 0.03-0.10 Hz frequency band.

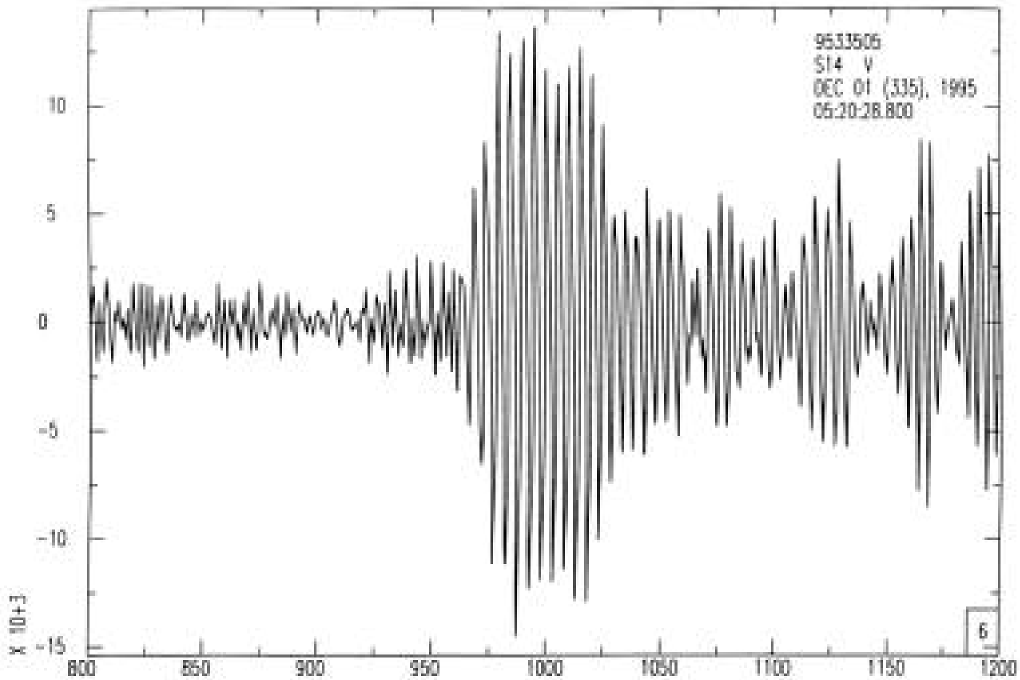

Figure 6. Vertical component seismogram on an OBS at a distance of 3195 km from an earthquake on the northern EPR. Bandpass filtered with corners at 0.15 and 0.5 Hz. The 5-to-6 s energy forms a prominent phase that is highly dispersed and scattered. It begins at an arrival time equivalent to a group velocity of about 3.3 km/s, equivalent to typical lower crustal shear wave velocities, and almost the same onset velocity for same period as the vertical record in figure 3, despite traveling in seafloor of somewhat greater average age.